Supernovae

The spectra of supernovae fall into many categories (see below), but beginning in about 1985, astronomers recognized that there were physically, only two basic types of supernovae: Type Ia and Type II.

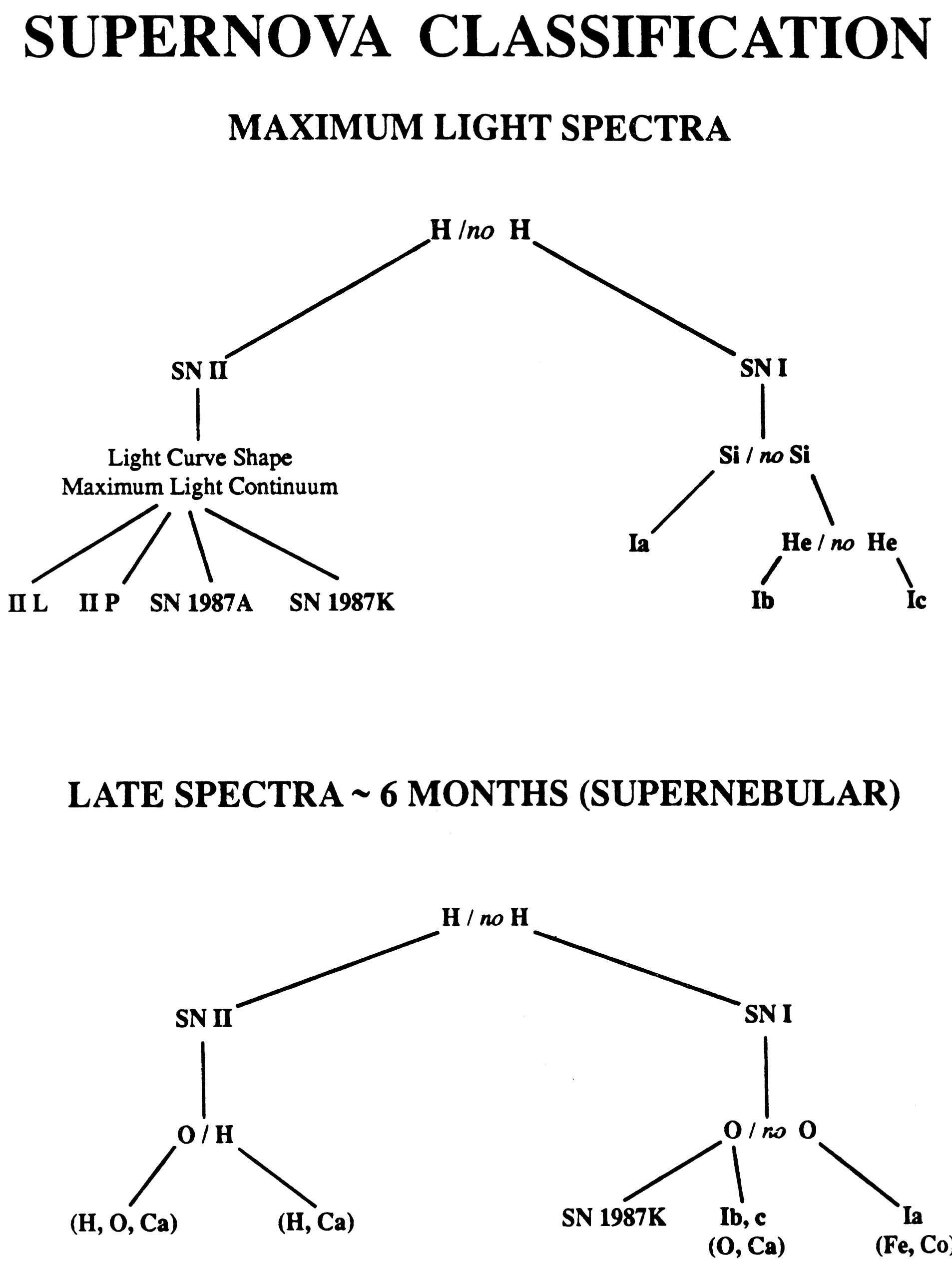


FIG. 1–A classification scheme for supernovae based on the early and late-time spectra and other features (from Harkness & Wheeler 1990).

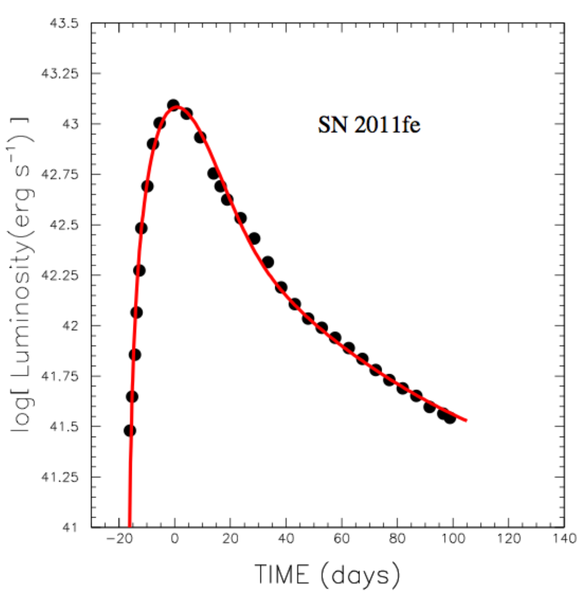
Type Ia Supernovae

Type Ia supernovae probably come from the ignition of a degenerate carbon-oxygen core. Since the core is degenerate, the star cannot adjust to the energy input (the energy goes into removing the degeneracy, rather than increased gas pressure), and in matter of milliseconds, a deflagration front propagates throughout the star. This causes photodisintegration rearrangement, with the result that the entire star becomes unbound (no remnant is produced), and, via the physics of photo-disintegration rearrangement, most of the star is converted to iron and iron-peak elements.

Photodisintegration rearrangement creates nuclear statistical equilibrium (i.e., the Saha equation applies), and much of the star is converted to ^{56}Ni. However, ^{56}Ni is radioactive: it quickly beta decays via the reactions

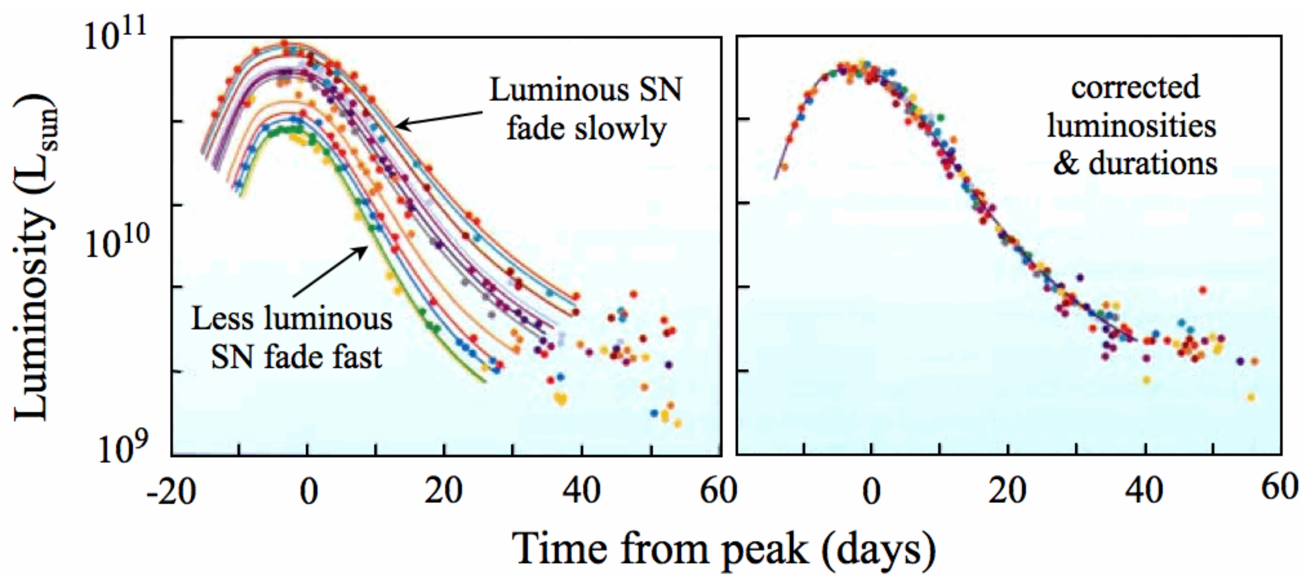
$$^{56}\text{Ni} \longrightarrow {}^{56}\text{Co} + e^-(1.72 \text{ MeV}) \quad \text{half life} \quad 6.1 \text{ Days}$$
$$^{56}\text{Co} \longrightarrow {}^{56}\text{Fe} + e^-(3.58 \text{ MeV}) \quad \text{half life} \quad 77.12 \text{ Days}$$

The electrons then interact with the surrounding medium, heat it up, and power the light curve.



The complete lack of hydrogen in the spectrum of a SN Ia strongly suggests that the progenitor of the star is a hydrogen-poor object, such as a white dwarf. But how does one get a white dwarf to explode? The two thoughts are 1) accretion onto a white dwarf from a companion star, and 2) the merger of two white dwarfs in a close orbit (due to oribtal decay from gravitational radiation).

The problem: surveys for double-degenerate binaries in the Milky Way have found no systems with a total mass greater than $1.4 M_{\odot}$ which will merge in a Hubble time. On the other hand, if accretion is responsible, one would think that all SN Ia would be virtually identical (as all would be exactly $1.4 M_{\odot}$). This is clearly not the case.



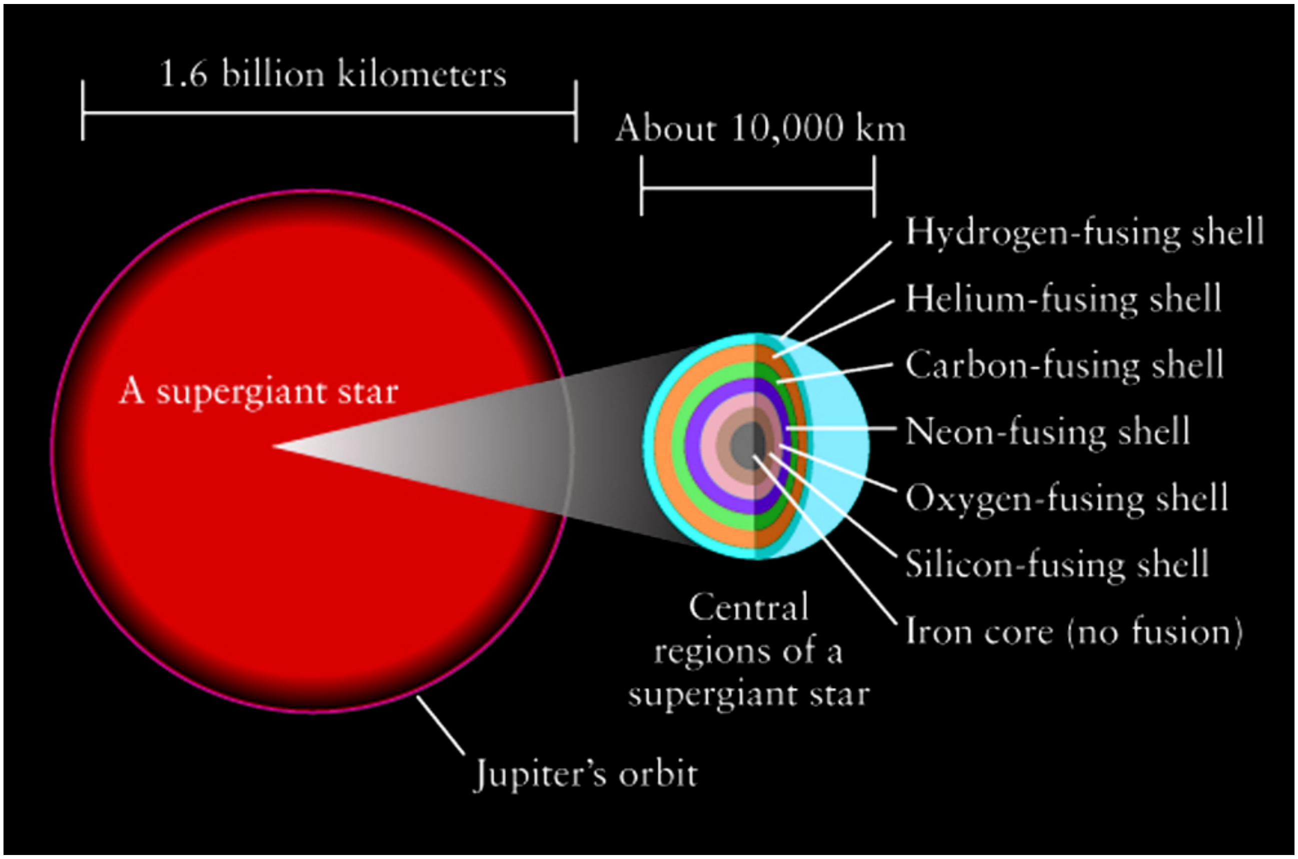
(One possible clue: the "underluminous" SN Ia are often found in elliptical galaxies, while the brightest SN Ia are generally in systems that have vigorous star formation.)

If SN Ia start from a $1.4\,M_{\odot}$ white dwarf, and are powered by the conversion of ^{56}Ni to ^{56}Fe, then the luminosity of the supernova at maximum must be proportional to the amount of ^{56}Ni that is produced. This, in turned should be proportional to the kinematic

energy of the explosion, which only depends on mass. Models indicate that the deflagration of a $1.4\,M_\odot$ white dwarf should produce $0.6 \pm 0.2 M_\odot$ of ^{56}Ni. In that case, the absolute luminosity of a SN Ia supernova should be $M_B \sim -19.6 \pm 0.5$.

Unfortunately, models are SN Ia have a great deal of uncertainty. It is clear that, the amount of ^{56}Ni is somewhere in the range between 0.2 and $1.4\,M_\odot$, but the exact number of model dependent. More importantly, the conversion from total luminosity to B (or V or I-band) luminosity depends on model atmospheres, and this is very uncertain. Because SN Ia do not have hydrogen, the radiative transfer is controlled by millions of metal lines. This makes the bolometric correction difficult to calculate.

Type II Supernovae



Type II (and Types Ib and Ic) supernovae are seen only in star-forming galaxies, and are thus thought to come from massive stars that have produced iron in their core. When a star's core becomes iron, there is no more energy to maintain hydrostatic equilibrium; the core collapses, and then rebounds, due to "core bounce" and the pressure of neutrinos. This imparts kinetic energy to the layers of mass on top of the core, causing the outside of the star to be ejected into space at speeds of $\sim 10,000$ km s^{-1}. The core itself becomes a neutron star or a black hole. Because the progenitors of Type II SN come from a very wide range of masses, their supernovae can vary in luminosity by orders of magnitude.

Note that much of the iron produced has a result of stellar evolution becomes locked up in the core remnant. Most of the the material

that is ejected into space are the layers on top of the star: the shells that were fusing hydrogen, helium, carbon, oxygen, etc. As a result, most of the metals produced by a Type II supernovae are α-process elements (^{12}C, ^{16}O, ^{20}Ne, etc.)

Type Ib and Ic supernovae are generally considered to be high-mass stars whose outer layers have been removed due to mass loss (either due to a companion interaction or enhanced mass loss). In SN Ib, the outer hydrogen layer has been lost; in SN Ic, both the hydrogen and helium layers are gone. Because there is less mass on top of the core, the ejection velocities of these supernovae are generally higher than those of other Type II objects. There is also some circumstantial evidence that SN Ic objects are associated with gamma-ray bursts.

Type II-L (linear) and P (plateau) describe the shape of a core collapse supernovae's light curve. Type II-L supernovae have probably lost most (but not all) of their outer hydrogen layers, allowing energy to escape rather easily. In Type II-P objects, the electrons ionized from hydrogen (by the shock wave) provide increased opacity and (for a time) trap the energy, causing a plateau in the light curve.

There have been four supernovae observed in the Milky Way: SN 185 (observed by Chinese astronomers), SN 1006 (which produced the Crab Nebula), SN 1572 (Tycho's supernova) and SN 1604 (Kepler's supernovae). In addition, a supernova probably occurred in the constellation of Casseopia in the late 17th century, but was unobserved.

The last two supernovae observed in the Local Group were SN 1885A in the bulge of M31, and SN 1987A in the Large Magellanic Cloud. The former (also known as S Andromeda) was observed by Hubble, and is the first object in the list of 85 "novae" he observed between 1885 and 1926. It was almost certainly a Type Ia object, and the iron produced in the event has been recovered (in absorption) via spectroscopy. SN 1987A was seen by the unaided eye, and is sometimes called Shelton's supernova, after the Las Campanas Observatory staff member who brought it the astronomer's attention. It was an underluminous core-collapse object whose progenitor was a blue supergiant (presumably because it lost most of its outer layers).